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BURN-RESISTANT AND HIGH TENSILE STRENGTH METAL ALLOYS

FIELD OF THE INVENTION

[0001] The present invention relates generally to metal alloys and more particularly to nickel-based alloys that are resistant to burning in oxygen-enriched environments and which have sufficient strength for structural applications.

BACKGROUND OF THE INVENTION

[0002] The current and proposed use of oxygen-rich and full-flow staged combustion rocket engine cycles imposes a significant challenge on the selection of materials for preburner and turbomachinery components. Most materials burn in the high pressure, flowing gaseous oxygen environment to which these components would be subjected. A major challenge for compatibility in these environments is the selection of structural materials which will not sustain combustion, i.e., are substantially burn resistant. Material selection options include protective coatings on materials that do not have inherent burn resistance to preclude burning within the given operating environment. The desired approach is to avoid the use of coatings and opt for materials that can survive in the operating environment, thereby increasing safety and reliability factors. In addition, selecting high strength materials allows for a streamlined design which is lighter weight and higher performance.

[0003] U.S. Patent Nos. 4,461,542 and 4,671,931, the entire specifications of which are incorporated herein by reference, disclose a nickel-chromium-aluminum-iron alloy commercially available under the tradename Haynes® 214™, which was developed as a high-temperature, oxidation-resistant

alloy. Although Haynes® 214™ is somewhat burn-resistant, it is substantially limited in structural applications due to its relatively low strength, and is therefore undesirable for rocket engine preburner and turbomachinery applications.

[0004] Another material of interest is Monel Alloy K-500™, which is a nonferrous alloy containing mainly nickel, copper, and aluminum. It is corrosion resistant and capable of hardening by heat treatment. Monel Alloy K-500™ has been used for gears, chains, and certain structural members in aircraft that are subjected to corrosive attacks. Although Monel Alloy K-500™ is burn resistant, it lacks desirable strength for high stress and high temperature rocket engine applications.

[0005] Another material of interest is Inconel MA 754™, which is an oxide dispersion strengthened nickel-chromium-iron-yttria-titanium-aluminum alloy which possesses high-temperature strength and creep resistance and has been used in gas turbine engineering and thermal processing applications. As with the previously described materials, it also does not possess desirable strength for high stress environments.

[0006] Finally, other materials such as the alloy 625 or Waspaloy™ have sufficient tensile strength for use in these rocket engine components or other high stress applications, however, they are limited in other key areas. In particular, these metal alloys do not exhibit sufficient burn resistance for use in the elevated temperature, high pressure oxygen environments. As a result, typical rocket engine structural materials such as Waspaloy™ are not considered viable candidate materials for the rocket engine applications of interest.

[0007] Therefore, there continues to exist a need for superior burn resistant and high tensile strength metal alloys for use in high temperature and high pressure oxygen environments. The preburner and hot turbine components in full-flow and oxygen-rich rocket engines produce both high temperature and high pressure oxygen environments and they are subjected to very high structural loads. Therefore, the materials selected for these components must possess both excellent resistance to burning and high tensile strength to survive and perform in this challenging environment. Such materials, are not generally known in the art.

SUMMARY OF THE INVENTION

[0008] The above disadvantages are solved and the following advantages are achieved by the present invention. A first advantage of the present invention is to provide a new and improved alloy that is resistant to burning in oxygen-rich environments yet is useful in structural applications.

[0009] A second advantage of the present invention is to provide a new and improved alloy that is particularly adaptable for use in oxygen-rich rocket engines.

[0010] Yet another advantage of the present invention is to provide a new and improved alloy that is useful in structural applications at operating temperatures ranging from room temperature to approximately 1200°F.

[0011] In accordance with a first embodiment of the present invention, a nickel-based alloy is provided, comprising: (1) about 55 to about 75 weight

percent nickel; (2) about 12 to about 17 weight percent cobalt; (3) about 4 to about 16 weight percent chromium; (4) about 1 to about 4 weight percent aluminum; and (5) about 1 to about 4 weight percent titanium.

[0012] In accordance with a second embodiment of the present invention, a nickel-based alloy is provided, comprising: (1) about 70 to about 75 weight percent nickel; (2) about 13.5 to about 16.5 weight percent cobalt; (3) about 6 to about 15 weight percent chromium; (4) about 1 to about 4 weight percent aluminum; and (5) about 1 to about 4 weight percent titanium.

[0013] In accordance with a third embodiment of the present invention, a nickel-based alloy is provided, comprising: (1) about 70 to about 75 weight percent nickel; (2) about 13.5 to about 16.5 weight percent cobalt; (3) about 6 to about 15 weight percent chromium; (4) about 1 to about 3 weight percent aluminum; and (5) about 1 to about 4 weight percent titanium.

[0014] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0016] Figure 1 is a graphical illustration of the Extinguishing Combustion Threshold as a function of tensile strength for prior art and embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0018] The present invention is comprised of various alloys having the following general composition: about 55 to about 75 weight percent nickel; about 12 to about 17 weight percent cobalt; about 4 to about 16 weight percent chromium; about 1 to about 4 weight percent aluminum; and about 1 to about 4 weight percent titanium. These embodiments, along with other embodiments, comprise various other minor components.

[0019] The alloys of the present invention may also contain manganese in amounts between about 0.15 to about 0.25 weight percent; silicone; carbon in amounts between about 0.01 to about 0.5 weight percent; boron in amounts between about 0.003 to about 0.009 weight percent; and zirconium in amounts between about 0.02 to about 0.07 weight percent.

[0020] The nickel component ensures superior burn resistance, and is far superior in terms of burn resistance relative to most other elemental metals that were previously tested. Embodiments of the present invention comprise levels of nickel in amounts of at least 50%. This level of nickel is generally used

to maintain superior burn resistance. One embodiment of the present invention comprises nickel weight percent in the range of about 70 to about 75.

[0021] Cobalt acts as a solid solution strengthener in the nickel matrix while maintaining superior burn resistance. Cobalt weight percent is in the range of about 12 to about 17.

[0022] Chromium is included to provide minimum oxidation resistance. An embodiment of the present invention comprises about 15 weight percent and helps maintain the alloy's superior burn resistance. The alloy of the present invention generally includes chromium weight percent in the range of about 6 to about 15.

[0023] The aluminum content aids in the oxidation resistance of the alloy while maintaining superior burn resistance. Further, the aluminum content contributes to the alloy's gamma prime strengthening mechanism. Aluminum comprises about 1 to about 3 weight percent of the alloy.

[0024] The titanium content contributes to the alloy's gamma prime strengthening mechanism and is present in the range of about 1 to about 4 weight percent.

[0025] Other minor elements such as boron, zirconium, and carbon may be present in the alloys according to the present invention. These additions typically segregate to the grain boundaries and impart strength which can be important during primary and secondary fabrication steps.

[0026] The nickel-based superalloys, such as those described are generally fabricated via a two-step melting sequence which involves vacuum

induction melting and vacuum arc remelting. This two-step process yields an alloy ingot which undergoes mechanical work to convert the ingot into billet, bar, sheet or plate.

[0027] The fact that the alloys of this invention possess an excellent combination of properties including burn resistance and superior strength in an oxygen-enriched environment is illustrated by the following examples:

EXAMPLE 1

[0028] An alloy having the weight percent composition of 71.5 nickel, 16.5 cobalt, 8.0 chromium, 1.5 aluminum and 2.5 titanium was prepared. The alloy has been tested in high-pressure environments generally more harsh than or similar to a full-flow staged combustion and oxygen-rich staged combustion rocket engine. This alloy exhibited both high tensile strength and high burn resistance. The results of the test of Example 1 are plotted in Figure 1 at data point Ex. 1. The tensile strength of Example 1 alloy is high enough for most rocket engine environments in both room temperature and high temperature applications and tests. Furthermore, the Example 1 alloy had a desirable burn resistance which allows it to survive the high pressure oxygen environment.

EXAMPLE 2

[0029] An alloy having the weight percent composition of 72.9 nickel, 16.6 cobalt, 8.1 chromium, 1.5 aluminum and 3.9 titanium was prepared. The alloy has been tested in high pressure gaseous oxygen environments generally more harsh than or similar to a full-flow staged combustion and oxygen-rich staged combustion rocket engine. The alloy exhibited both high tensile and high

burn resistance. The results of the test of Example 2 are plotted in Figure 1 at data point Ex. 2. The tensile strength of Example 2 alloy is high enough for most rocket engine environments in both room temperature and high temperature applications and tests. Furthermore, the Example 2 alloy has a desirable burn resistance which allows it to exist in high pressure oxygen environments.

[0030] Figure 1 illustrates the superior properties of several alloy variations according to the present invention. It is to be understood that the data points Ex. 1 and Ex. 2 are merely exemplary of the present invention. The Extinguishing Threshold Pressure is the maximum pressure of gaseous oxygen at which the alloy will self extinguish as measured by the Promoted Combustion test. This test is used to determine if a material, in the configuration of a one-eighth inch rod, will sustain or extinguish combustion in a high pressure, gaseous oxygen environment. It is a test typically used to screen metals for burn resistance in oxygen. The tensile strength is determined through a typical tensile test which involves imparting a tensile load on a standardized specimen and determining at what stress the specimen fails. Superior behavior in both tests is desired for oxygen-rich rocket engine applications. Alloys which do not sustain combustion at or above 6000 pounds per square inch (psi) gaseous oxygen and which exhibit as much strength as possible are desired. Alloys with lower strengths may be used in some instances, but the resulting structure generally sacrifices lightweight and high performance properties.

[0031] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended

to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

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